Influences of Athletic Footwear on Ground Reaction Forces During A Sidestep Cutting Maneuver on Artificial Turf

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ABSTRACT

Background: Recreational athletes can select their desired footwear based on personal preferences of shoe properties such as comfort and weight. Commonly worn running shoes and cleated footwear with similar stud geometry and distribution are worn when performing sport-specific tasks such as a side-step cutting maneuver (SCM) in soccer and American football (hereafter, referred to as football). The effects of such footwear on injury mechanics have been documented with less being known regarding their effect on performance. **Objective:** The purpose of this study was to examine performance differences including peak ground reaction forces (pGRF), time-to-peak ground reaction forces (tpGRF) and the rate of force development (RFD) between football cleats (FB), soccer cleats (SOC), and traditional running sneakers (RUN) during the braking and propulsive phases of a SCM. **Methodology:** Eleven recreationally active males who participated in football and/or soccer-related activities at the time of testing completed the study. A 1 x 3 [1 Condition (SCM) x 3 Footwear (RUN, FB, SOC)] repeated measures ANOVA was utilized to analyze the aforementioned variables. **Results:** There were no significant differences (p > 0.05) between footwear conditions when comparing pGRF, tpGRF, or RFD in either the braking or propulsive phases. **Conclusion:** The results suggest that the studded and non-studded footwear allowed athletes to generate similar forces over a given time frame when performing a SCM.

Key words: Shoes, Football, Soccer, Athletes, Running

INTRODUCTION

The shoe-surface interface defines how an athlete's footwear interacts with the underlying playing surface assisting with the implementation of sport-specific movements such as sprinting, cutting, and stopping. The mechanism allowing this interaction lies in the understanding of vertical and horizontal resistive forces. Vertical resistive forces determine a cleats ability to penetrate a playing surface (Driscoll, Kelley, Kirk, Koerger, & Haake, 2015) which can be influenced by surface hardness as well as cleat design (i.e., stud geometry) (Clarke & Carré, 2010). Surface hardness is the ability of a surface to absorb impact energy upon it being struck by an

object (SportsTurf Managers Associations [STMA], 2008). When the energy is created by an athlete's foot, the reactionary force can be referred to as a ground reaction force (GRF). Traction, which comprises the horizontal resistive force and can be referred to as grip-ability, describes how cleated footwear resists the motion of the body relative to the surface (McNitt, Middour, & Waddington, 1997).

Cleats are frequently worn in soccer and football as they play a vital role in an athlete's performance during these sports. Approximately 265 million athletes participate in soccer globally (Fédération Internationale de Football Association [FIFA], 2007); it is accepted to be the most popular sport in the world. Football also maintains its popularity

with over one million reported male high school football athletes in the United States (National Federation of State High School Associations, 2017). The increase in participation within both sports has provided shoe manufacturers incentive to develop various cleat designs exclusively for tasks related to a specific sport and position in attempt to improve performance. Cleat differences vary between models and manufacturers with stud geometry (i.e. cylindrical, conical, prismatic, and bladed) and distribution (i.e. turf, artificial grass, hard ground, firm ground, and soft ground) being the differentiating variables (Sterzing, 2016). However, recreational athletes can select their own footwear and are not limited to footwear specific to their sport.

Cleated footwear is designed to assist with foot and ankle stabilization while simultaneously improving an individuals ability to perform sport-specific movements, such as a side-step cutting maneuver (SCM), by allowing for a strong push-off in any direction without slipping (Sterzing, 2016). The SCM is utilized in both sports and is described as a high-speed evasive movement with a sudden change in direction, often at an angle of approximately 45º relative to the running direction (Havens & Siward, 2015; McLean, Neal, Myers, & Walters, 1999; Vanrenterghem, Venables, Pataky, & Robinson, 2012). Within the SCM, two phases exist which enable the change in direction to occur: the braking and propulsion phases. The braking phase occurs from the instance of foot contact until the pGRF and is responsible for assisting with the body's negative acceleration to prepare for a rapid change in direction. The subsequent propulsion phase allows the athlete to generate velocity in the newly intended direction, which occurs in the time between the braking pGRF and foot toe-off. Numerous variables have been associated with effecting lower extremity mechanics and performance during a SCM such as footwear design, cleat arrangements, shoe-surface interaction (Kent, Forman, Lessley, & Crandall, 2015b), cutting angle (Havens & Sigward, 2015), and approach speed (Vanrenterghem et al. 2012). Previous literature has shown that prolonged activity may also effect performance due to the decrease in the neuromuscular response and/or control as the duration of playing time may increase (McGovern et al., 2015).

Injuries within both sports arise due to several factors with a common mechanism stemming from the increasing size, speed, and strength of the athletes. This may indirectly alter the traction developed from cutting with a foot planted while the upper body rotates. Among male high school athletes, game and practice injury rates were highest for football and soccer to the foot and ankle, representing 15.9% and 33.5% of all reported injuries, respectively (Powell & Barber-Foss, 1999). In 2005, the rate of lower limb injuries among high school male athletes was the highest in football while soccer had the highest rate among females with common injuries including sprains (50%), strains (17%), contusions (12%), and fractures (5%) (Fernandez, Yard, Comstock, 2007). Within the sport of soccer, 42% of all injuries are due to intrinsic player-controlled factors such as muscle weakness, while 24% of injuries were due to poor playing surfaces combined with "inferior shoes" (Nigg,

1989). These injuries can arise due to intrinsic risk factors, such as lack of experience, position within the sport, biological age, and joint flexibility combined with extrinsic factors such as shoe-surface interaction, field conditions, and equipment (Dvorak & Junge, 2000; Iacovelli et al., 2013).

While previous research has examined how a SCM and cleated footwear alters injury possibilities, the effect they have on performance variables have not been as widely analyzed, with the exception of a few studies (Brock et al., 2014; Durá, Hoyos, Martinez, & Lozano, 1999; McGhie & Ettema, 2008; Meijer, Dethmers, Savelberg, Willems, & Wijers, 2006; Queen et al. 2008). The GRFs exerted against a cleats sole is vital for understanding how quickly and forcefully an athlete can run and change direction. Previous research on artificial turf analyzing GRFs is scarce with (Saggini & Vecchiet, 1994) evaluating soccer footwear on natural turf at a speed of 2.8 m s^{-1}. However, the latter study did not report footwear characteristics, data filtering techniques, surface thickness, nor how the surface was attached to the force platforms. Similarly, it has also been found that studded cleats produce significantly larger peak impact values compared to bladed cleats and turf shoes during sport-specific movements (McGhie & Ettema, 2013), while GRFs were found to be equal in magnitude on different types of turf with the same fourteen studded cleat (Verhelst et al., 2008). Ultimately, past studies have failed to investigate the GRFs produced while wearing cleated footwear with similar stud configurations designed for different sports. Therefore, the purpose of this study was to examine the performance differences in mediolateral and vertical peak GRF (pGRF), time-to-peak GRF (tpGRF), and the rate of force development (RFD) in football cleats (FB), soccer cleats (SOC), and traditional running shoes (RUN) during the braking and propulsive phases of a SCM on artificial turf. It was hypothesized that the FB cleats would produce larger pGRF, tpGRF, and RFD in the mediolateral direction due to the position of bladed cleats at the medio-lateral surface of the outsole while SOC would produce larger values in the vertical direction. Athletes had previously perceived bladed cleats to increase the interaction between the footwear and the surface during the SCM due to a larger contact area (Sterzing, 2016).

METHODOLOGY

Participants

An a-priori analysis using data from the male subjects in Butler et al. (2014) estimated twelve participants were needed based off the following input parameters: ß=.20, α=.05, effect size =.38, and non-sphericity correction of 1.0 while including 9 different measures of 3 groups with an estimated correlation of 0.3 across the measurements. Twelve participants were recruited and completed the study; however, eleven healthy male participants (Age: 21.8 ± 1.5 years; Height: 1.81 ± 0.05 m; Weight: 87.8 ± 14.4 kg) were used for analysis due to equipment malfunction. All participants were actively engaged in football and/or soccer-related activities such as practices, drills, or games at a competitive recreational level while wearing cleats for a minimum of 1 hour per week within the last year. All participants were Exercise

Science students recruited from various classes. Participants were excluded if they had a history of any lower extremity musculoskeletal injury within the past six months or a lower extremity reconstructive surgery within the past three years. The study was approved by the Institutional Review Board (IRB) at The University of Mississippi. Prior to collection, participants were screened for musculoskeletal, orthopedic, and cardiovascular anomalies using the Physical Activity Readiness Questionnaire (PAR-Q) by the American College of Sports Medicine (2013).

Procedures

Participants were tested in all three types of footwear (FB, SOC, RUN) with the order determined by a counterbalanced design. All participants completed a dynamic warm-up (Cazás-Moreno et al., 2015) with additional self-directed stretching of the trunk and lower extermity, if desired. Upon conclusion of the warm-up and prior to testing in each footwear, participants were allowed as many warmup repetitions of the SCM as necessary. This allowed the participants to adapt to the shoe-surface interaction in order to mimic game-like speed and technique. Participants began in an upright standing start position and were instructed to run towards the force platform at full speed from a distance of 4.57m away to mimic the initial start in a pro-agility drill. An orange cone was placed on the opposite side of the force platform to indicate the location in which they were supposed to plant their foot and perform the SCM. Within each type of footwear, participants were instructed to complete a SCM on their dominant (kicking) leg. The dominant foot made contact with the force platform while they cut and pushed-off in the opposite direction (i.e., right leg dominance: right foot contacts the force platform while participants cut to the left). Similar to previous studies (Smith, Dyson, & Janaway, 2004; Queen et al., 2008), the testing protocol had participants perform between 5-10 SCM in all three footwear conditions until three successful trials occurred. If numerous trials were deemed successful, the first three were used for analysis. A successful trial was defined as when the participant's entire foot made contact with the force platform. To avoid fatigue, a 30-second rest between SCM trials was allotted as well as a 10-minute break between shoe conditions where participants were instructed to sit down without shoes to act as a washout period.

Instrumentation

A 0.4m x 0.4m AMTI OR6-6 (AMTI, Inc., Watertown, MA, USA) force platform embedded into the floor captured GRFs during foot contact at 1000 Hz. Data were filtered using a fourth-order Butterworth with a cutoff frequency set at 15Hz. Vinyl tile covered the force platform matching the rest of the capture volume to reduce targeting. Similar to previous studies (Bennett, Brock, Brosnan, Sorochan, & Zhang, 2015; Brock et al., 2014; Durá, Hoyos, Martinez, & Lozano, 1999), a 1.83m x 8.54m strip of synthetic turf (AstroTurf, Dalton, GA) with a Styrene-Butadiene Rubber (SBR) infill was securely attached to the force platform and runway via Industrial Strength Extreme VELCRO® (Manchester, NH, USA) (Figure 1). Another 1.83m x 8.54m strip of synthetic turf, comprised of the same material, was cut into two 1.83m x 4.27m strips and was placed parallel to the primary runway.

Footwear

The procedures carried out by each participant were completed in a traditional runnning shoe [Nike Dart], soccer cleat [Nike Tiempo Rio II FG], and football cleat [Nike Alpha Strike 2 TD] (Figure 2). Running shoes acted as a control between the cleated footwear conditions while also imitating recreational athletes not utilizing cleated footwear during competition. The footwear for this study was selected based on the popularity of use with local Division-I National Collegiate Athletic Association (NCAA) athletes. Footwear characteristics are listed in Table 1 with the average shoe size worn by the participants being eleven (U.S. sizing). All cleats utilized were new at the time of testing and were properly fitted and laced by the researchers to minimize variability in lacing techniques. No mechanical data were available on footwear differences.

Data Analysis

The first three successful trials collected were averaged to calculate pGRF, tpGRF, and RFD for each participant in all three footwear conditions. All variables of interest were calculated in both the braking and propulsion phases of the SCM in the mediolateral and vertical directions. pGRF was the largest magnitude along the mediolateral and vertical axes. tpGRF depicts the total length of time it takes a participant to reach their peak magnitude. This variable during the braking phase
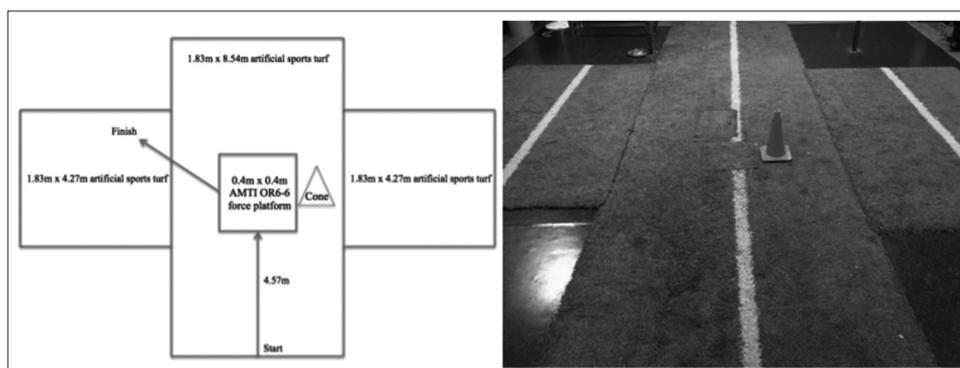
Figure 1. Experimental Setup

Figure 2. Footwear: Nike Alpha Strike 2 TD Football Cleat (FB); Nike Tiempo Rio II FG Soccer Cleat (SOC); Nike Dart Running Shoe (RUN)

Table 1. Footwear characteristics

	Football cleat (FB)	**Soccer cleat (SOC)**	**Running shoe (RUN)**
Mass (kg)	0.318	0.213	0.289
Total # of studs	12	12	n/a
Mid-forefoot stud height (cm)	1.6	1.7	n/a
Medial/lateral forefoot stud height (cm)	2.1	2	n/a
Rearfoot stud height (cm)	2.1	2.4	n/a

looked at the time from initial foot contact (defined as when force increased 1N above body weight) to peak brake, while the propulsion phase was estimated from the time it took from the peak brake time to the peak propulsion time. RFD was determined by the amount of force produced over the change in time within each direction and phase of the SCM (Cazás-Moreno et al., 2015; Haff, Ruben, Lider, Twine, & Cormie, 2015). All kinetic data were normalized to each participant's body weight (N) to allow for comparative analysis.

Statistical Analysis

A 1x3 [1 Condition (SCM) x 3 Footwear (RUN, FB, SOC)] repeated-measures analysis of variance (ANOVA) with an alpha level set at 0.05 was used to measure the effects of the three types of footwear on pGRF, tpGRF, and RFD. If a significant main effect of footwear was found, a Bonferroni post-hoc adjustment was used. Intra-class correlation coefficients (ICC) were then calculated as a reliability measure due to the presence of artificial turf on the force platforms. All analyses were conducted using the SPSS 21 statistical software package (IBM SPSS® Statistics V21.0, Armonk, NY, USA).

RESULTS

There were no statistically significant differences (p>0.05) between footwear when comparing mediolateral and vertical pGRF, tpGRF, or RFD in either the braking or propulsive phases of a SCM (Table 2). However, significant ICCs were present for pGRF in the mediolateral and vertical directions during the braking and propulsion phase as well as RFD in both directions during the braking phase (Table 3).

DISCUSSION

The purpose of this study was to examine the performance differences in mediolateral and vertical pGRF, tpGRF, and

RFD in FB cleats, SOC cleats, and running shoes during the braking and propulsive phases of a SCM on artificial turf. It was hypothesized that the FB cleat would produce larger pGRF, tpGRF, and RFD in the mediolateral direction while the SOC cleat would produce larger values in the vertical direction. The results from this study indicate that there were no statistical differences in any of the kinetic variables of interest between footwear in both the braking and propulsion phases of a SCM. This suggests that footwear, with or without studs, allowed athletes to generate comparable GRFs in a similar time frame. More specifically, football and soccer cleats with similar stud characteristics allow individuals to generate similar forces over a given time frame when performing a SCM. Although no significant differences were present, SOC cleats allowed participants to produce greater forces in the braking and propulsion phase within the mediolateral and vertical directions, respectively. Similarly, SOC cleats had allowed participants to generate faster tpGRF in both directions and phases except for the propulsion phase in the mediolateral direction. This may be explained by the fact the SOC cleat had longer mid-forefoot studs and a lighter mass compared to the FB cleat. Footwear that is lighter with longer studs may provide a greater depth of penetration allowing for a greater shoe-surface interaction; therefore, eliciting greater force production in a shorter time period.

In regard to surfaces, previous literature has shown that artificial turf generates greater peak horizontal forces in translational movements, peak torques in rotation movements, and peak vertical forces in translation/drop tests relative to natural turf (Kent, Forman, Crandall, & Lessley, 2015a). However, since artificial turf has been shown not to tear or divot, the maximum force measured is limited to the maximum force produced by an individual (Kent et al., 2015a). This indicates that varying results may be due to participants' lower extremity strength and experience performing the SCM. Similarly, the exact depth of the infill

Table 2. Kinetic variables of a SCM

Variable (units)	Football cleat (FB)	Soccer cleat (SOC)	Running shoe (RUN)	F-value	η_p^2
Mediolateral braking					
pGRF (BW)	1.55 (0.03)	1.68 (0.24)	1.55 (0.41)	(F (1.447, 14.467)=1.374, P=0.275)	0.121
tpGRF (s)	0.237 (0.052)	0.217 (0.019)	0.214 (0.008)	(F (1.166, 11.661)=1.557, P=0.241)	0.135
RFD (BW/s)	6.81 (1.88)	7.74 (0.98)	7.26 (1.93)	(F (1.393, 13.932)=1.640, P=0.228)	0.141
Vertical braking					
pGRF (BW)	3.86 (0.7)	3.82 (0.7)	3.5 (1.3)	(F (1.368, 13.684)=1.439, P=0.262)	0.126
tpGRF (s)	0.249 (0.052)	0.225 (0.019)	0.224 (0.006)	(F (1.210, 12.096)=2.268, P=0.156)	0.185
RFD (BW/s)	16.04 (4.25)	17.09 (3.43)	15.75 (6.07)	(F (1.734, 17.340)=0.682, P=0.499)	0.064
Mediolateral propulsion					
pGRF (BW)	1.66 (0.24)	1.65 (0.25)	1.57 (0.28)	(F (1.464, 14.638)=1.225, P=0.308)	0.109
tpGRF (s)	0.025 (0.012)	0.033 (0.024)	0.037 (0.012)	(F (1.657, 16.572)=1.148, P=0.331)	0.103
RFD (BW/s)	78.97 (48.7)	59.62 (40.66)	46.2 (12.86)	(F (1.584, 12.673)=1.558, P=0.246)	0.163
Vertical propulsion					
pGRF (BW)	2.45 (0.42)	2.52 (0.45)	2.57 (0.81)	(F (1.903, 19.026)=1.198, P=0.198)	0.019
tpGRF (s)	0.078 (0.024)	0.065 (0.035)	0.066 (0.03)	(F (1.838, 18.380)=0.820, P=0.446)	0.076
RFD (BW/s)	31.15 (10.51)	54.49 (48.83)	36.62 (19.52)	(F (1.309, 11.783)=1.476, P=0.258)	0.141

Data are expressed as means (± SD). Variables: peak ground reaction force (pGRF); time-to-peak ground reaction force (tpGRF); rate of force development (RFD). Units: Body weight (BW), Seconds (s). No significant differences were found between footwear (p>0.05).

Table 3. Intraclass correlation coefficients (ICC)

Variable (units)	ICC	p-value	Confidence intervals	
			Lower bound	Upper bound
Mediolateral braking				
pGRF (BW)	0.801*	0.001	0.448	0.942
tpGRF (s)	−0.063	0.519	−1.948	0.689
RFD (BW/s)	0.727*	0.007	0.243	0.920
Vertical braking				
pGRF (BW)	0.865*	<0.001	0.626	0.961
tpGRF (s)	0.227	0.298	−1.143	0.774
RFD (BW/s)	0.841*	<0.001	0.559	0.954
Mediolateral propulsion				
pGRF (BW)	0.888*	<0.001	0.689	0.967
tpGRF (s)	−0.453	0.724	−3.031	0.575
RFD (BW/s)	−0.484	0.708	−3.637	0.636
Vertical propulsion				
pGRF (BW)	0.722*	0.007	0.228	0.919
tpGRF (s)	0.408	0.153	−0.642	0.827
RFD (BW/s)	−0.177	0.583	−2.448	0.682

Variables: peak ground reaction force (pGRF); time-to-peak ground reaction force (tpGRF); rate of force development (RFD). Units: Body weight (BW), Seconds (s). *Denotes *P*<0.05

and extraneous components that help create the turf construct could alter results. Results from this study are consistent with previous findings (Bennett et al., 2015; Brock et al., 2014; Gehring, Rott, Stapelfeldt, Gollhofer, 2007; Smith et al., 2004) when looking at GRF for various cleats and sport-specific movements. Results showed no differences in vertical pGRF between footwear conditions in this

study. This is supported by Brock et al. (2014) who found no significant differences among peak vertical ground reaction forces and loading rates between natural and synthetic turf cleats, while values were significantly larger when performing a 90° cut versus a 180° cut. Brock et al. (2014) reported values of 5.0 body weight (BW), 5.0 BW, and 4.8 BW for peak vertical GRF in a synthetic turf cleat, natural turf cleat,

and running shoe, respectively. Similarly, mediolateral GRF were consistent with 1.4 BW, 1.3 BW, and 1.3 BW, while time-to-peak GRF measured 0.050 s, 0.047 s, and 0.048 s within the same footwear conditions. Values are consistent with, yet slightly higher than the current study; however, the protocol carried out by Brock et al. (2014) had participants complete a single jump followed by a 90° SCM immediately upon landing, potentially accounting for the discrepancies in GRF measurements and impact forces compared to straight-line running.

Differences in RFD were not found between footwear conditions; however, this was expected due to its two calculating variables, force and time, not exhibiting significance. Normalized RFD values have shown to be nearly 103.0 BW/s in running shoes, synthetic turf cleats, and natural turf cleats (Brock et al., 2014) and as low as 21.32 BW/s while wearing a six-studded soccer cleat (Smith et al., 2004). Results match closely with those of the latter study (Smith et al., 2004) taking into account the various phases of the SCM. Smith et al. (2004) reported a loading rate of 21.32 BW/s and 26.09 BW/s for training shoes and soccer cleats, respectively; whereas the current study reports values of 15.75 BW/s and 17.09 BW/s. Utilizing a mechanical device to measure the coefficient of friction of various surfaces and comparing the forces from a 180° turning movement, Dura et al. (1999) concluded that surfaces do not influence maximum GRF, impulse, or total time. However, more time was ultimately spent in the braking phase, similar to the current study, when the frictional force was higher between the cleat and playing surface, while less time was needed to propel the athlete in the desired direction (Durá et al., 1999). During a SCM, a greater frictional force leads to an increase in joint torque; however, while an increase in torque may cause injuries at a joint, added time in the braking phase allows the knee to flex to a greater degree acting as a protective mechanism (Durá et al.,1999). This may indicate that athletes alter their movement based on the shoe-surface interaction.

Often critiqued, placing artificial turf over a force platform will not compromise data. Written in *FIFA Quality Concept for Football Turf: Handbook of Test* Methods (2009) and reported in McGhie et al. (2013), force platform data averaged a mean peak impact which was 98.7% ± 1.2% (range, 98.0-99.8%) of the average recorded by a mechanical apparatus across all artificial turf meeting Fédération Internationale de Football Association (FIFA) standards. It should be noted that this study was limited to a small sample size and it did not control for the participants' approach/running speed and cutting angle to reflect natural on-field SCM mechanics of each participant. However, it has been shown that technique is more important than running speed or cutting angle in regards to preventing injury since it alters posture, muscle activation, and preparation time when it is controlled (Besier, Lloyd, Cochrane, & Ackland, 2001). Future studies should consider the stresses placed on lower extremity joints during a SCM through a kinematic analysis to determine if cleated footwear designed for different sports alter force production. This, in combination with the current study, could potentially provide athletes information to select appropriate and desired footwear without compromising functional comfort for performance or injury risk.

CONCLUSION

To our knowledge, this is the first study to break down the SCM into two distinct phases and analyze how athletic cleats designed for different sports affect kinetic variables in a vertical and mediolateral direction. The SCM is one of many common techniques that allows an athlete to excel on the playing field. It is critical to understand the affect different footwear may have on vertical and mediolateral force generation to assist athletes, parents, and coaches to choose footwear that provides traction to perform the sport movement effectively. The current study suggests commonly worn cleated and non-cleated footwear produce similar GRFs, tpGRFs, and RFD during the braking and propulsion phase of a SCM. While all three types of footwear are providing traction, the similarities between kinetic variables indicate no one footwear analyzed provided specific performance advantages to an athlete in order to rapidly slow down or "brake" and accelerate during a SCM. Future research should examine various cleats with different stud variations to understand how the GRF affect kinematics at the lower extremity.

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